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Levels-of-Growing-Stock Cooperative Study in Douglas-Fir: Report No. 9 —

Some Comparisons of DFSIM Estimates With Growth in the Levels-of-Growing-Stock Study

Robert O. Curtis

Levels-of-growing-stock study treatment schedule, showing percent of gross basal area increment of control plot to be retained in growing stock

Thinning	Treatment 1	2	3	4	5	6	7	8
	Percent							
First	10	10	30	30	50	50	70	70
Second	10	20	30	40	50	40	70	60
Third	10	30	30	50	50	30	70	50
Fourth	10	40	30	60	50	20	70	40
Fifth	10	50	30	70	50	10	70	30

Background

Public and private agencies are cooperating in a study of eight thinning regimes in young Douglas-fir stands. Regimes differ in the amount of basal area allowed to accrue in growing stock at each successive thinning. All regimes start with a common level-of-growing-stock established by a conditioning thinning.

Thinning interval is controlled by height growth of crop trees, and a single type of thinning is prescribed.

Nine study areas, each involving three completely random replications of each thinning regime and an unthinned control, have been established in western Oregon and Washington, U.S.A., and on Vancouver Island, British Columbia, Canada. Site quality of these areas varies from I through IV.

LEVELS-OF-GROWING-STOCK COOPERATIVE STUDY IN DOUGLAS-FIR:

Report No. 9—Some Comparisons of DFSIM Estimates With Growth in the Levels-of-Growing-Stock Study

Robert O. Curtis, Principal Mensurationist
Pacific Northwest Research Station
Forestry Sciences Laboratory, Olympia, Washington

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Abstract

Curtis, Robert O. 1987. Levels-of-growing-stock cooperative study in Douglas-fir: Report No. 9--Some comparisons of DFSIM estimates with growth in the levels-of-growing-stock study. Res. Pap. PNW-RP-376. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 34 p.

Initial stand statistics for the levels-of-growing-stock study installations were projected by the Douglas-fir stand simulation program (DFSIM) over the available periods of observation. Estimates were compared with observed volume and basal area growth, diameter change, and mortality. Overall agreement was reasonably good, although results indicate some biases and a need for revision of the upper density limit in the DFSIM program.

KEYWORDS: Simulation, projections (stand), model validation, statistics (stand), growing stock (-increment/yield, Douglas-fir, *Pseudotsuga menziesii)*.

Summary

Initial stand statistics for the levels-of-growing-stock (LOGS) study installations were projected by the Douglas-fir stand simulation program (DFSIM) over the available periods of observation. Thinnings were simulated by use of observed top height trends, actual residual basal areas, and actual ratios of cut tree diameters to stand diameter before cutting (d/D). Estimates were compared with observed gross and net volumes and basal area growth, net change in quadratic mean diameter, and change in number of trees. Although the LOGS installations include regimes quite different from those in most of the data used to construct DFSIM, overall agreement was reasonably good. Results indicate some density-related bias in the thinned stands and a need for revision in the method used to control the maximum density in the DFSIM program and in the associated mortality estimates.

Other LOGS (Levels-of-Growing-Stock) Reports

Williamson, Richard L.; Staebler, George R. 1965. A cooperative level-of-growing-stock study in Douglas-fir. Portland, OR: U.S.Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 12 p.
Describes purpose and scope of a cooperative study which is investigating the relative merits of eight different thinning regimes. Main features of six study areas installed since 1961 in young stands are also summarized.

Williamson, Richard L.; Staebler, George R. 1971. Levels-of-growing-stock cooperative study on Douglas-fir: Report No. 1—Description of study and existing study areas. Res. Pap. PNW-111. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 12 p.
Thinning regimes in young Douglas-fir stands are described. Some characteristics of individual study areas established by cooperating public and private agencies are discussed.

Bell, John F.; Berg, Alan B. 1972. Levels-of-growing-stock cooperative study on Douglas-fir: Report No. 2—The Hoskins study, 1963-1970. Res. Pap. PNW-130. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 19 p.
A calibration thinning and the first treatment thinning in a 20-year-old Douglas-fir stand at Hoskins, Oregon, are described. Data tabulated for the first 7 years of management show that growth changes in the thinned stands were greater than anticipated.

Diggle, P.K. 1972. The levels-of-growing-stock cooperative study in Douglas-fir in British Columbia (Report No. 3, Cooperative L.O.G.S. study series). Inf. Rep. BC-X-66. Victoria, BC: Canadian Forestry Service, Pacific Forest Research Centre. 46 p.

Williamson, Richard L. 1976. Levels-of-growing-stock cooperative study in Douglas-fir: Report No. 4—Rocky Brook, Stampede Creek, and Iron Creek. Res. Pap. PNW-210. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 39 p.
The USDA Forest Service maintains three of nine installations in a regional, cooperative study of influences of levels of growing stock (LOGS) on stand growth. The effects of calibration thinnings are described for the three areas. Results of first treatment thinning are described for one area.

Berg, Alan B.; Bell, John F.1979. Levels-of-growing-stock cooperative study on Douglas-fir: Report No. 5—The Hoskins study, 1963-1975. Res. Pap. PNW-257. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 29 p.
The study dramatically demonstrates the capability of young Douglas-fir stands to transfer the growth from many trees to few trees. It also indicates that at least some of the treatments have the potential to equal or surpass the gross cubic-foot volume of the controls during the next treatment periods.

Arnott, J.T.; Beddows, D. 1981. Levels-of-growing-stock cooperative study in Douglas-fir: Report No. 6—Sayward Forest, Shawnigan Lake. Inf. Rep. BC-X-223. Victoria, BC: Canadian Forestry Service, Pacific Forest Research Centre. 54 p.
Data are presented for the first 8 and 6 years at Sayward Forest and Shawnigan Lake, respectively. The effects of the calibration thinnings are described for these two installations on Vancouver Island, British Columbia. Results of the first treatment thinning at Sayward Forest for a 4-year response period are also included.

Williamson, Richard L.; Curtis, Robert O. 1984. Levels-of-growing-stock cooperative study in Douglas-fir: Report No. 7—Preliminary results; Stampede Creek, and some comparisons with Iron Creek and Hoskins. Res. Pap. PNW-323. Portland, OR: U.S. Department ofAgriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 42 p.
Summaries are given through the first treatment period for the Stampede Creek LOGS study in southwest Oregon. Results are compared with two more advanced LOGS studies and, in general, are similar. To age 43, thinning in this low site III Douglas-fir stand resulted in some reduction in volume growth and moderate gains in diameter growth. Growth was strongly related to level of growing stock. Desirable density levels are recommended for young Douglas-fir stands.

Curtis, Robert O.; Marshall, David D. 1986. Levels-of-growing-stock cooperative study in Douglas-fir: Report No. 8—The LOGS study: twenty-year results. Res. Pap. PNW-356. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 113 p.
Authors review history and status of LOGS study and provide new analyses of data, primarily from the site II intallations. Growth is strongly related to growing stock. Thinning treatments have produced marked differences in volume distribution by tree size. At the fourth treatment period, current annual increment is still about double mean annual increment. Differences among treatments are increasing rapidly. There are considerable differences in productivity among installations, beyond those accounted for by site index differences. The LOGS study design is evaluated.

Contents

Introduction

The Douglas-fir stand simulator DFSIM (Curtis and others 1981, 1982) is widely used for coast Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*) in the Pacific Northwest. Limited comparisons with other data sets and with other simulators (Mitchell 1986, Mitchell and Cameron 1985) indicate that DFSIM estimates are in reasonable overall agreement with growth observed in several data sets, and with predictions from some other stand simulators.

Management options for new plantations and for intensively managed young stands, however, include regimes that are radically different from past practice and often outside the range of the data used in constructing DFSIM. The basic data used for DFSIM were mostly from natural stands. The data base available (1974) for this and alternate models contained relatively little information from stands with wide initial spacing, from older plantations, from stands with systematic thinning begun at an early age, or from stands with repeated fertilization. There are questions concerning the applicability of the current version of DFSIM to stands that have had early stocking control followed by systematic repeated thinning, and to stands established or maintained at much lower densities than was common practice in the past.

Preliminary results of some work done under the Forest Intensified Research (FIR) program in southwest Oregon[1] indicate that DFSIM slightly underestimates volume growth and overestimates mortality for the small research plots used in these fertilizer and fertilizer-thinning studies, and that these selected uniform stands frequently attain higher densities than predicted by DFSIM. A greater cause for concern is a tendency to underestimate response to thinning, compared with the preliminary analyses for southwest Oregon.

The levels-of-growing-stock (LOGS) study (Curtis and Marshall 1986) provides an extensive set of consistent, high-quality data for stands with early stocking control, subsequent intensive systematic thinning, a range of growing stock that includes much lower levels than were common in the past, and an extended period of observation. Because the LOGS studies use small, uniform plots and closely controlled treatments, the plots probably approximate the upper limit of growth for the specified regimes.

The LOGS regimes do not directly represent practical management options, and comparisons with LOGS data cannot provide a complete answer to the question of DFSIM's applicability to future intensively managed stands. Comparisons of observed growth from the LOGS study with DFSIM predictions, however, should indicate the model's ability to predict stand development for these regimes and may indicate the nature and magnitude of changes needed.

This report presents comparisons of DFSIM estimates with actual growth on the LOGS installations. Similar comparisons are briefly noted for two other available data sets representing plantations with a wide range in initial stocking.

The LOGS Data

The LOGS data have been described in detail by Curtis and Marshall (l986) and previous authors (Arnott and Beddows 1981; Bell and Berg 1972; Berg and Bell 1979; Diggle 1972; Williamson 1976; Williamson and Curtis 1984; Williamson and Staebler 1965, 1971). Some additional data from recent measurements at the Stampede Creek, Iron Creek, and Clemons studies, not used in previous analyses, were also available.

[1] Data and analyses (study C-53) on file at Forestry Sciences Laboratory, Olympia, WA.

The LOGS studies include eight thinning treatments plus an untreated control treatment. There are three 1/5-acre plots in each treatment (four control plots in the Skykomish study) in a completely random arrangement. The stands were selected for initial uniformity and had had little competition before the study was established, as was shown by live crowns extending over most of the bole. In most installations the stand was 20-40 feet in height at the time of establishment, slightly taller in some instances.

The thinned plots received an initial calibration thinning that reduced all treated plots in an installation to a single density level, usually about 400 stems per acre. Subsequent treatment thinnings, made at intervals of 10 feet of height growth, retained specified percentages of the gross basal area growth observed on the controls (table, inside front cover). Treatments 1, 3, 5, 7 (the "fixed" treatments) retained 10, 30, 50, and 70 percent, respectively; treatments 2, 4, 6, and 8 retained percentages that varied for successive treatment thinnings.

The "calibration period" is the period from the calibration thinning to the first treatment thinning. Subsequent periods are referred to as "treatment periods."

The available data consisted of the data for the calibration period at all installations, plus data for the following numbers of treatment periods by installation:

Site class	Installation	Treatment periods
II	Iron Creek	4
	Clemons	5
	Hoskins	5
	Francis	4
	Skykomish	5
III	Stampede	2
	Sayward	2
IV	Rocky Brook	2
	Shawnigan	1

Although early measurements (before 1974) from several LOGS installations were included in the data used to construct DFSIM, these were a small part of the data and of the range of densities now available and constituted a very minor portion of the total DFSIM data base. The LOGS data are almost--but not quite--an independent data set.

Methods

Simulation estimates can be compared with observed growth in many ways. A limited number of comparisons must be chosen that appear meaningful in terms of the objective of primary concern and are consistent with the limitations of the data available.

Comparisons with a data set such as LOGS, limited in size and geographic range as well as in the range of initial conditions and treatments covered, cannot give a generally applicable estimate of overall bias and error. The objective of these comparisons was not to produce such an estimate, but to look for features of simulator behavior inconsistent with this data set and possibly indicative of a need to modify the simulator. Therefore, these comparisons rely primarily on simple averages and graphic comparisons rather than on formal statistical tests, and results are suggestive rather than conclusive.

Comparisons must take into account the structure of the simulator, so that differences between estimates and observation can be related to specific characteristics of the model.

Height Growth

Height growth is one of the major driving variables in DFSIM, and the simulator provides alternate height growth estimation procedures. Regional height growth curves generate heights and height growth, given age and site index; however, an option is provided that allows substitution of local height growth trends, if known. Three procedures are possible:

1. Use the regional curves corresponding to the site estimate based on height at the beginning of the simulation.

   This is the most realistic procedure if the objective is projection of existing stands of intermediate age. This method will give very inaccurate estimates when applied to young stands because site index estimates made in young stands are very unreliable.

2. Use the regional curve corresponding to the site estimate based on the age nearest the index age.

   This is reasonable if the objective is comparison of regimes on land of known site index, with no knowledge of the local height growth trend.

3. Use observed height growth trends for individual stand.

   This will give the most accurate estimates but requires information that is often not available.

Because DFSIM already provides for modifying the height growth curve when the necessary information is available, questions primarily concern the performance of the routines estimating diameter growth, basal area growth, volume growth, and mortality. Because procedure 3 eliminates considerable extraneous variation and because the information needed to apply it is available for the LOGS data, it was adopted for these comparisons.

Observed top height (H40) trends were smoothed to eliminate minor irregularities caused in part by measurement error and to provide height growth curves "correct" for the given location. A regression, of the form $H = a + b(\text{age}) + c(\text{age})^2$, was fitted to the estimates of top height for successive ages. The resulting curve, specific to the individual stand, was used as the "observed height trend" in DFSIM projections.

Grouping of Plots

Comparisons used means of the three plots in each treatment within each installation. Only treatments 1, 3, 5, 7 ("fixed percentage" thinning treatments) and the control were included. These restrictions were adopted to simplify computations and comparisons and because the "variable percentage" treatments do not clearly correspond to readily interpretable differences in stand density.

Management Regime

Management regime must be accounted for in the simulations. Because basal area was the primary thinning control in the LOGS studies, it seemed reasonable to use basal area in combination with the d/D ratio (ratio of quadratic mean diameter of trees

cut to quadratic mean diameter of stand before cutting). Therefore, the principal comparisons were made using (1) observed height trends, smoothed as above; and (2) actual number of trees and basal area at the beginning of the simulation. Each successive thinning was made at the same age as in the corresponding LOGS data; d/D ratios and residual basal areas were identical to those in the corresponding actual thinning. Thus, deviations of projections from the observed LOGS statistics are the result of cumulative differences in basal area growth, volume growth, mortality, and diameter growth.

Projection Routines

DFSIM uses different projection routines for the juvenile stand (quadratic mean diameter (D) less than 5.6 inches) and the main stand (quadratic mean diameter 5.6 inches or larger), and comparisons must be subdivided accordingly.

Comparison Groups

The comparisons with LOGS data were divided into four groups:

1. Thinned, treatment periods, main stand routine (D equal to or greater than 5.6 inches).

2. Thinned, calibration period. At all installations except Stampede Creek, this includes only the juvenile stand routine.

3. Control, main stand routine (D equal to or greater than 5.6 inches).

4. Control, juvenile stand (D less than 5.6 inches).

Comparisons for LOGS Thinned Treatments

Analysis

Treatment periods (main stand routine).—Beginning with the actual number of trees and basal area at the beginning of the first treatment period in which diameter was 5.6 inches or larger, stands were projected to the age of the most recent measurement, separately for each thinning treatment, by installation. The resulting projection periods in years are shown in table 1.

Thinning treatments were simulated by reducing the stand to the same residual basal area as the corresponding LOGS treatment, with d/D ratio equal to that in the actual LOGS thinning. Numbers of trees and diameters were not controlled after the simulation was begun, which allowed errors to accumulate in a manner similar to that in practical applications of the simulator.

An adjusted age was used for the Francis study, calculated as age at breast height (b.h.) plus 7 years, rather than recorded stand age. This adjustment was made because DFSIM uses in its calculations an age at b.h. calculated as total age minus 7 years for site II. Adjusted ages are shown in the tables.

The resulting estimates of gross volume growth, gross basal area growth, net change in stand average diameter and number of trees, and cumulative mortality in volume and basal area are shown in tables 1 through 4, together with corresponding actual values from the LOGS data. Actual values are graphically compared with DFSIM estimates in figures 1 through 7.

Table 1--Comparison of observed gross volume growth and mortality with DFSIM estimates for main stand routine projections for thinning treatments 1, 3, 5, and 7

Site	Installation	Projection period	Treat-ment	Gross volume increment: Observed	Gross volume increment: DFSIM	Gross volume increment: Observed/DFSIM	Mortality volume: Observed	Mortality volume: DFSIM	Ratio, mortality volume/ gross volume increment: Observed	Ratio, mortality volume/ gross volume increment: DFSIM
		years		— ft³/acre —			— ft³/acre —			
II	Iron Creek	14	1	2,831	3,094	0.92	153	15	0.054	0.005
			3	3,800	3,686	1.03	120	18	.032	.005
			5	4,573	4,371	1.05	88	46	.019	.011
			7	5,103	4,718	1.08	211	122	.041	.026
	Hoskins	17	1	4,607	4,496	1.02	0	22	0	.005
			3	5,860	5,512	1.06	0	28	0	.005
			5	7,217	6,205	1.16	125	122	.017	.020
			7	8,130	6,524	1.25	83	221	.010	.034
	Clemons	14	1	2,512	2,510	1.00	10	12	.004	.005
			3	3,269	3,385	.97	30	16	.009	.005
			5	3,562	3,401	1.05	234	26	.066	.008
			7	3,804	3,739	1.02	152	93	.040	.025
	Francis	16	1	2,938	3,227	.91	11	15	.004	.005
			3	4,186	4,391	.95	10	21	.002	.005
			5	5,563	5,433	1.02	159	44	.029	.008
			7	6,184	5,902	1.05	10	125	.002	.021
	Skykomish	18	1	4,369	4,100	1.07	13	21	.003	.005
			3	5,477	4,624	1.18	46	23	.008	.005
			5	6,673	5,365	1.24	48	115	.007	.021
			7	7,306	5,854	1.25	160	250	.022	.043
III	Stampede Creek	10	1	2,133	1,898	1.12	1	9	0	.005
			3	2,322	2,253	1.03	2	12	0	.005
			5	2,372	2,211	1.07	0	26	0	.012
			7	2,692	2,515	1.07	5	51	.002	.020
	Sayward	8	1	1,319	1,531	.86	0	7	0	.005
			3	1,533	1,708	.90	0	8	0	.005
			5	1,721	1,975	.87	0	9	0	.005
			7	1,952	1,926	1.01	0	14	0	.007
IV	Rocky Brook	13	1	1,530	1,874	.82	11	8	.007	.004
			3	1,728	2,189	.79	93	9	.054	.004
			5	1,868	2,331	.80	68	21	.036	.009
			7	2,409	2,644	.91	62	48	.026	.018
	Shawnigan	6	1	674	786	.86	0	3	0	.004
			3	813	870	.93	0	4	0	.005
			5	858	944	.91	4	4	.005	.004
			7	900	891	1.01	21	6	.023	.007

Table 2--Comparison of observed gross basal area growth and mortality with DFSIM estimates for main stand routine projections for thinning treatments 1, 3, 5, and 7

Site	Installation	Projection period	Treat-ment	Gross basal area increment			Basal area mortality		Basal area mortality/ gross basal area increment	
				Observed	DFSIM	Observed/DFSIM	Observed	DFSIM	Observed	DFSIM
		years		— ft²/acre —			— ft²/acre —			
II	Iron Creek	14	1	85.5	95.5	0.90	7.1	0.6	0.083	0.006
			3	104.3	106.3	.98	5.4	.7	.051	.007
			5	115.8	107.1	1.08	3.6	1.6	.031	.015
			7	125.6	108.4	1.16	8.7	4.1	.069	.038
	Hoskins	17	1	125.1	122.4	1.02	0	.8	0	.007
			3	147.4	135.6	1.09	0	1.0	0	.007
			5	170.0	131.9	1.29	3.8	3.7	.022	.028
			7	182.4	130.7	1.40	2.6	6.6	.014	.050
	Clemons	14	1	66.8	71.4	.94	.4	.4	.006	.006
			3	80.4	85.7	.94	1.0	.6	.013	.007
			5	93.7	86.2	1.09	12.1	.9	.129	.010
			7	86.2	84.0	1.03	5.6	3.0	.064	.036
	Francis	16	1	92.1	108.5	.85	.6	.6	.007	.006
			3	122.3	132.5	.92	.6	.8	.004	.006
			5	143.7	140.5	1.02	6.3	1.5	.044	.011
			7	169.4	146.7	1.15	.5	4.5	.003	.031
	Skykomish	18	1	100.4	93.1	1.08	.5	.6	.005	.006
			3	128.5	101.2	1.27	1.4	.7	.011	.007
			5	137.6	102.4	1.34	1.8	3.1	.013	.030
			7	156.7	109.6	1.43	4.6	6.8	.029	.062
III	Stampede Creek	10	1	51.8	45.3	1.14	.1	.3	.002	.007
			3	54.5	50.0	1.09	.1	.4	.002	.008
			5	55.0	46.0	1.20	0	.8	0	.017
			7	57.8	48.5	1.19	1.1	1.5	.019	.031
	Sayward	8	1	41.1	51.4	.80	0	.3	0	.006
			3	47.2	55.6	.85	0	.3	0	.005
			5	51.4	61.0	.84	0	.4	0	.007
			7	54.2	55.2	.98	0	.6	0	.011
IV	Rocky Brook	13	1	53.4	61.5	.87	.6	.2	.012	.003
			3	58.8	70.2	.84	4.9	.4	.083	.006
			5	63.8	70.1	.91	3.9	.9	.061	.013
			7	76.7	73.7	.04	3.2	1.9	.042	.026
	Shawnigan	6	1	22.3	28.2	.79	0	.2	0	.007
			3	25.0	30.6	.82	0	.2	0	.007
			5	27.7	32.6	.85	.2	.2	.008	.006
			7	29.3	29.5	.99	1.0	.3	.033	.010

Table 3--Net change in quadratic mean diameter (D) for main stand routine projections for thinning treatments 1, 3, 5, and 7

Site	Installation	Projection period	Treatment	Initial D, before cut	Final D, before cut		Net diameter increment		Net diameter increment: ratio,
					Observed	DFSIM	Observed	DFSIM	Observed / DFSIM
		years		inches					
II	Iron Creek	14	1	6.37	13.80	14.86	7.43	8.49	0.88
			3	6.56	12.61	12.22	6.05	5.66	1.07
			5	6.69	11.92	11.44	5.23	4.75	1.10
			7	6.65	11.17	11.04	4.52	4.39	1.03
	Hoskins	17	1	6.68	17.79	17.30	11.11	10.62	1.05
			3	6.75	15.48	14.62	8.73	7.87	1.11
			5	6.59	13.96	12.12	7.37	5.53	1.33
			7	6.93	13.47	11.63	6.54	4.70	1.39
	Clemons	14	1	7.09	14.30	14.65	7.21	7.56	.95
			3	6.85	12.87	13.44	6.02	6.59	.91
			5	6.55	10.85	10.40	4.30	3.85	1.12
			7	6.54	9.86	9.84	3.32	3.30	1.01
	Francis	16	1	6.75	16.69	19.13	9.94	12.38	.80
			3	6.90	14.95	15.62	8.05	8.71	.92
			5	6.74	12.84	12.73	6.10	5.99	1.02
			7	6.56	11.66	11.29	5.10	4.73	1.08
	Skykomish	18	1	6.87	17.57	16.34	10.70	9.47	1.13
			3	6.45	15.77	13.22	9.32	6.77	1.38
			5	6.54	13.13	11.32	6.59	4.78	1.38
			7	6.87	13.16	11.49	6.29	4.62	1.36
III	Stampede Creek	10	1	7.86	11.91	11.49	4.05	3.63	1.12
			3	7.95	11.89	11.52	3.94	3.57	1.10
			5	7.97	10.76	10.42	2.79	2.45	1.14
			7	8.04	10.66	10.22	2.62	2.18	1.20
	Sayward	8	1	6.06	8.98	9.66	2.92	3.60	.81
			3	6.22	8.68	9.29	2.46	3.07	.80
			5	6.33	8.76	9.31	2.43	2.98	.82
			7	6.31	8.47	8.55	2.16	2.24	.96
IV	Rocky Brook	13	1	5.31	9.61	10.09	4.30	4.78	.90
			3	5.33	8.38	8.81	3.05	3.48	.88
			5	5.22	7.96	8.11	2.74	2.89	.95
			7	5.27	8.11	8.06	2.84	2.79	1.02
	Shawnigan	6	1	5.80	7.53	7.86	1.73	2.06	.84
			3	5.93	7.38	7.68	1.45	1.75	.83
			5	5.97	7.35	7.58	1.38	1.61	.86
			7	5.82	6.97	6.99	1.15	1.17	.98

Table 4--Net change in number of trees for main stand routine projections for thinning treatments 1, 3, 5, and 7

Site	Installation	Projection period	Treat-ment	Initial number, before cut	Final number, before cut		Net change in number of trees		Final number of trees: ratio,
					Observed	DFSIM	Observed	DFSIM	Observed / DFSIM
		years		number per acre					
II	Iron Creek	14	1	343	77	72	266	271	1.07
			3	340	145	145	195	195	1.00
			5	338	207	225	131	113	.92
			7	347	283	305	64	42	.93
	Hoskins	17	1	352	52	56	300	296	.93
			3	342	102	114	240	228	.90
			5	363	165	215	198	148	.77
			7	328	223	283	105	45	.79
	Clemons	14	1	235	57	58	178	177	.98
			3	282	105	100	177	182	1.05
			5	332	188	215	144	117	.87
			7	365	283	288	82	77	.98
	Francis	16	1	235	45	38	190	197	1.18
			3	243	97	92	146	151	1.05
			5	340	185	187	155	153	.99
			7	400	292	299	108	101	.98
	Skykomish	18	1	338	50	59	288	279	.85
			3	375	92	126	283	249	.73
			5	362	172	218	190	144	.79
			7	348	205	247	143	101	.83
III	Stampede Creek	10	1	292	130	133	162	159	.98
			3	287	150	157	137	130	.96
			5	282	203	207	79	75	.98
			7	277	228	239	49	38	.95
	Sayward	8	1	355	165	155	190	200	1.06
			3	355	218	204	137	151	1.07
			5	355	252	238	103	117	1.06
			7	355	310	307	45	48	1.01
IV	Rocky Brook	13	1	232	130	135	102	97	.96
			3	323	228	235	95	88	.97
			5	368	318	325	50	43	.98
			7	392	370	370	22	22	1.00
	Shawnigan	6	1	375	215	214	160	161	1.00
			3	373	260	256	113	117	1.02
			5	375	297	295	78	80	1.01
			7	375	362	364	13	11	1.00

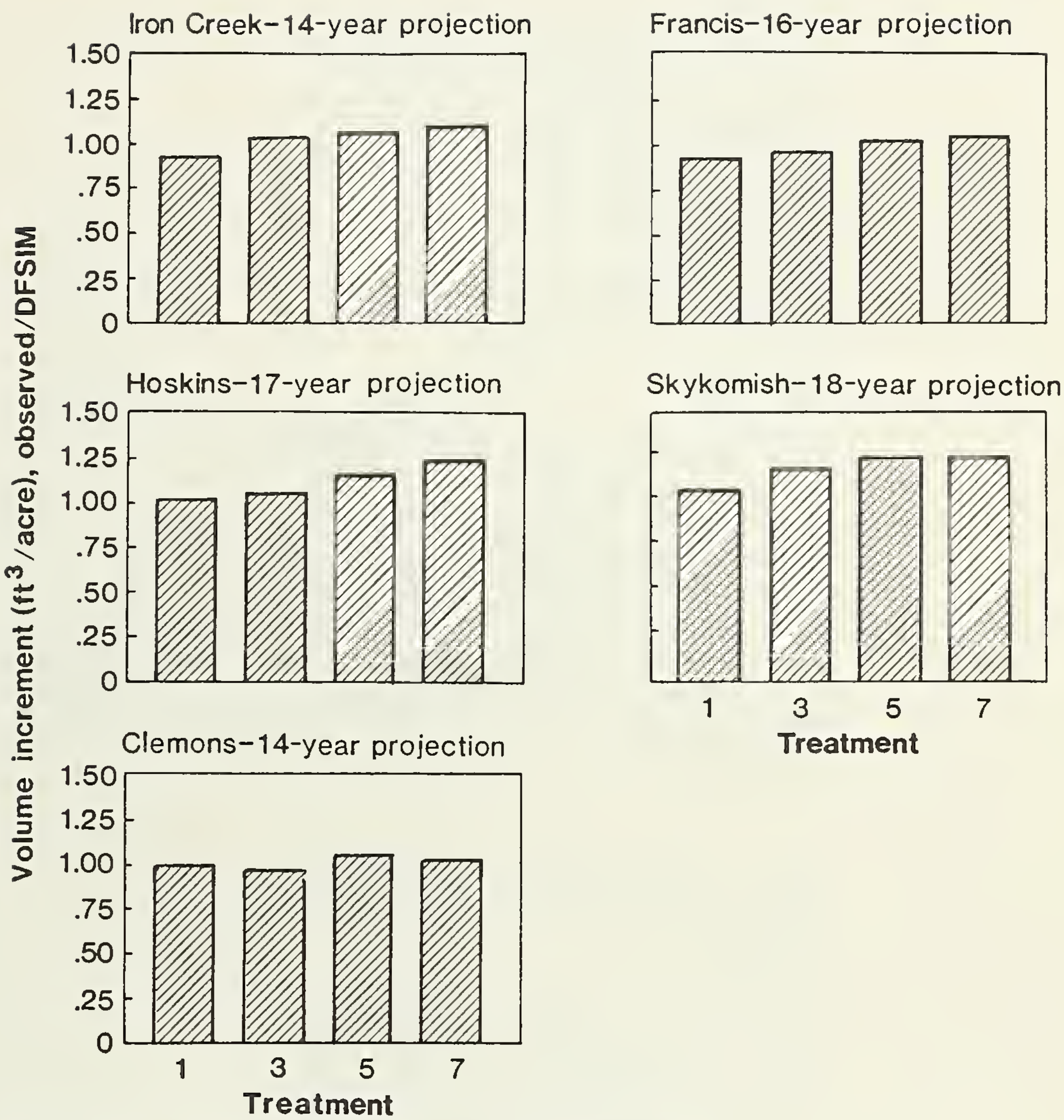

Figure 1—Ratios of observed gross volume growth to DFSIM estimates, by treatment within installation, on thinned plots, main stand routine. A. Site II installations.

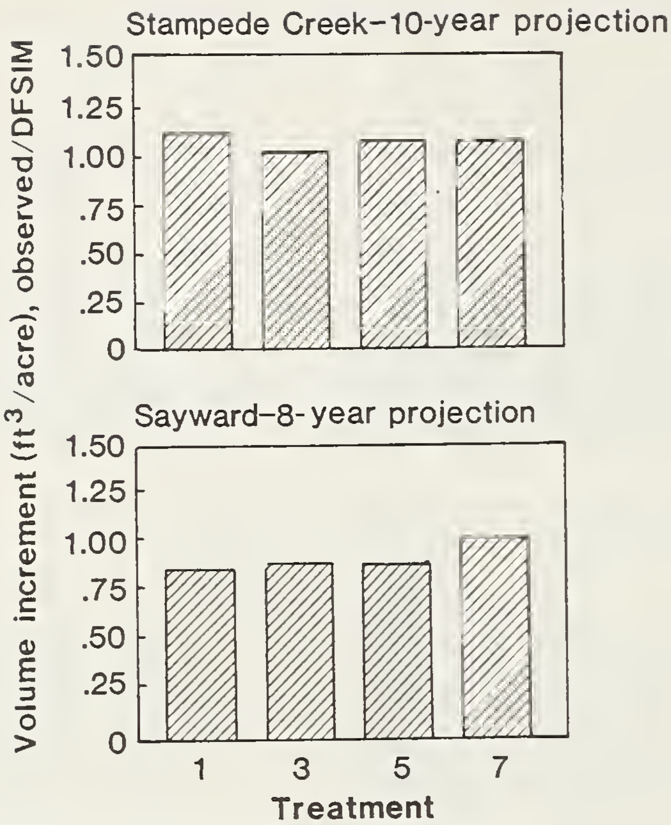

Figure 1 (continued)—B. Site III installations.

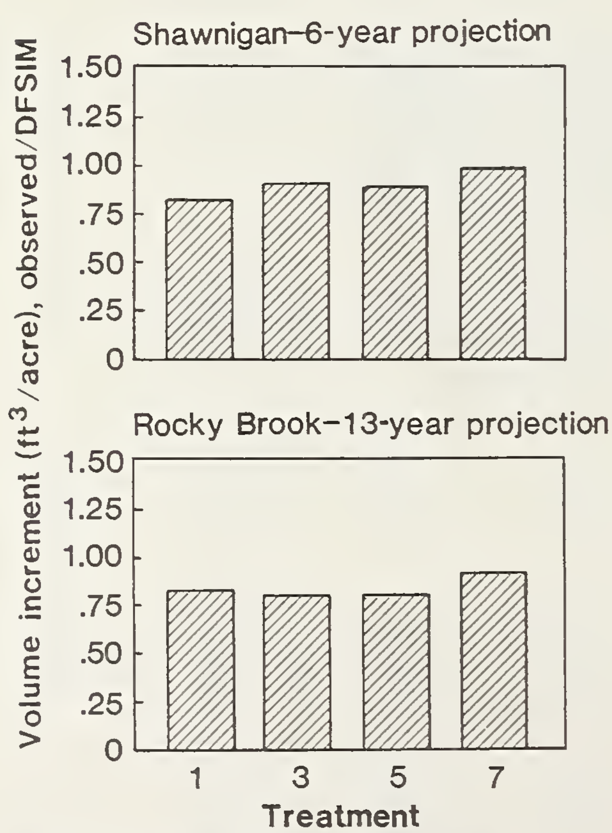

Figure 1 (continued)—C. Site IV installations.

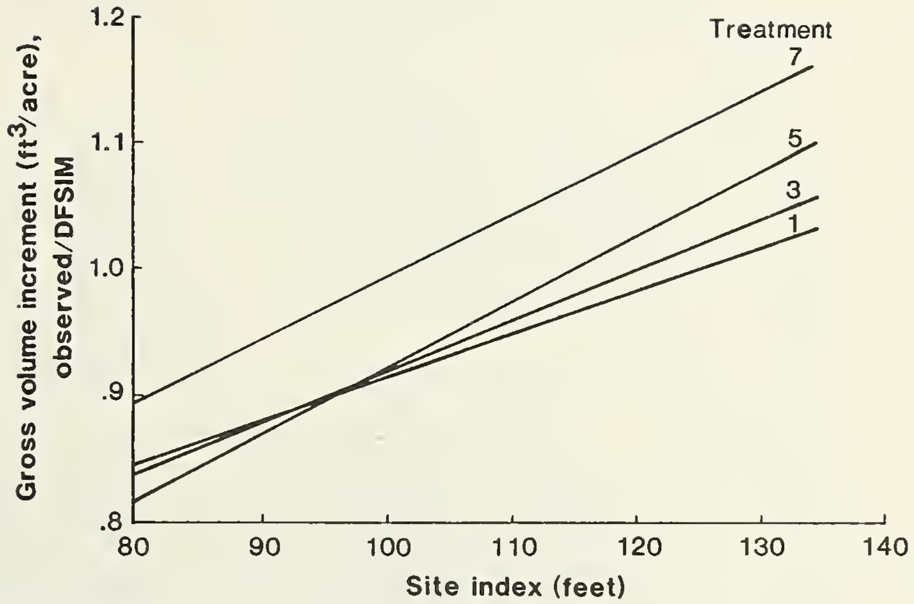

Figure 2—Regressions of ratios of observed/DFSIM gross volume increment (table 1) on site index, fit to values for eight installations (excluding Skykomish), by treatment.

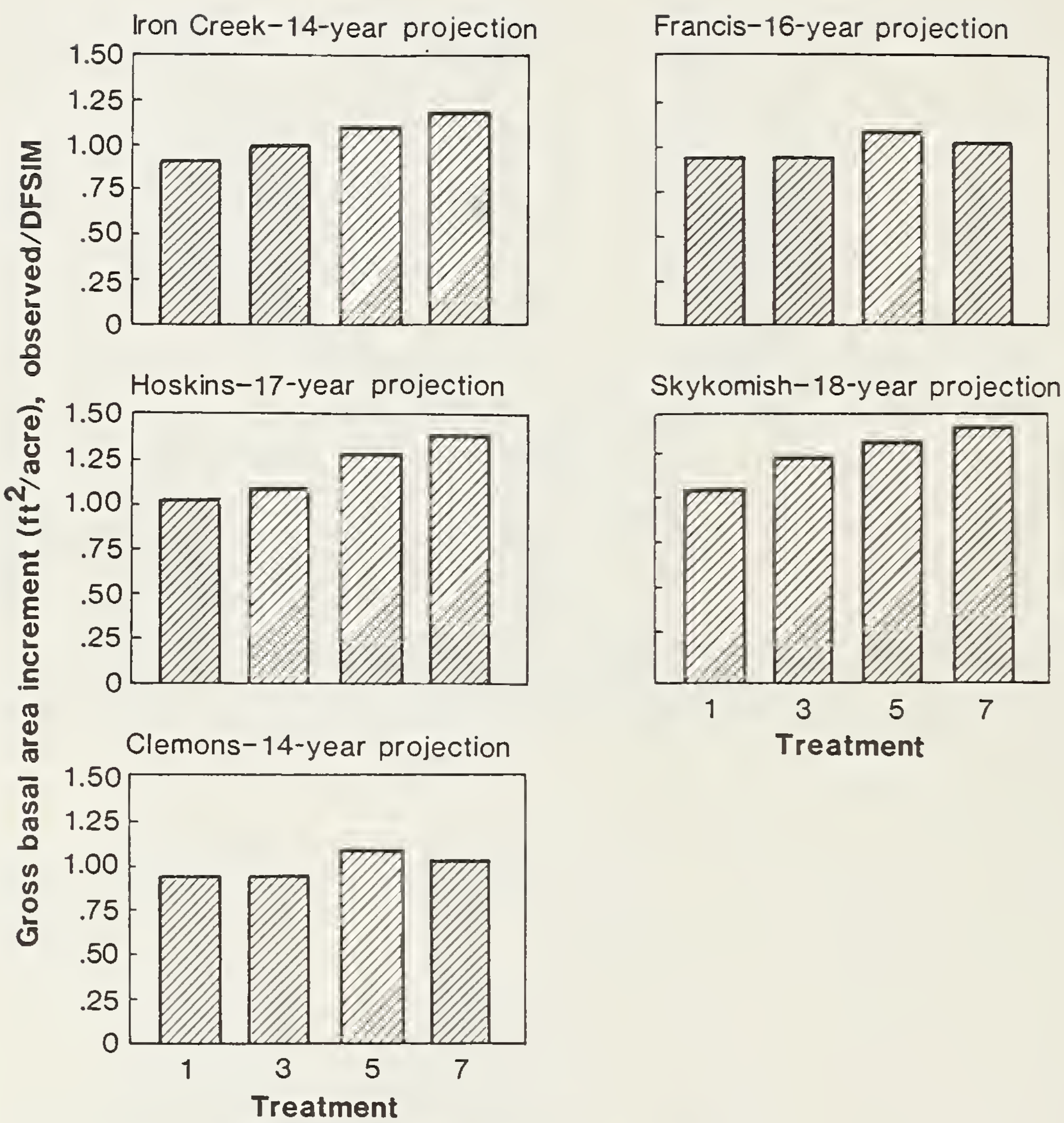

Figure 3—Ratios of observed gross basal area growth to DFSIM estimates, by treatment within installation, thinned plots, main stand routine. A. Site II installations.

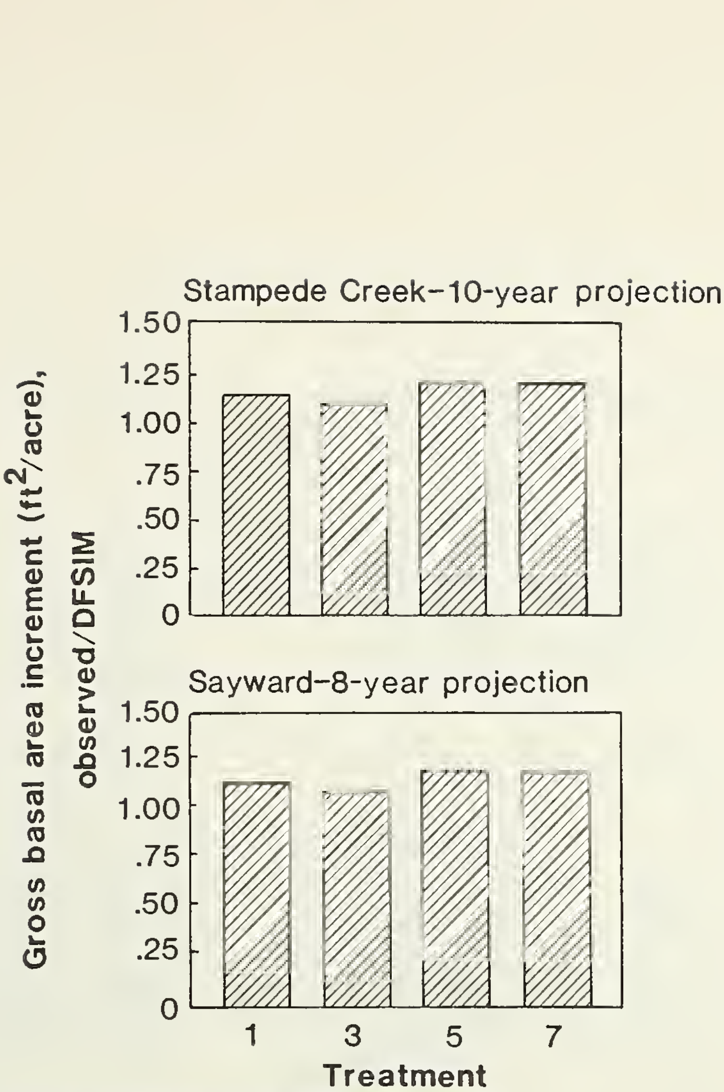

Figure 3 (continued)—B. Site III installations.

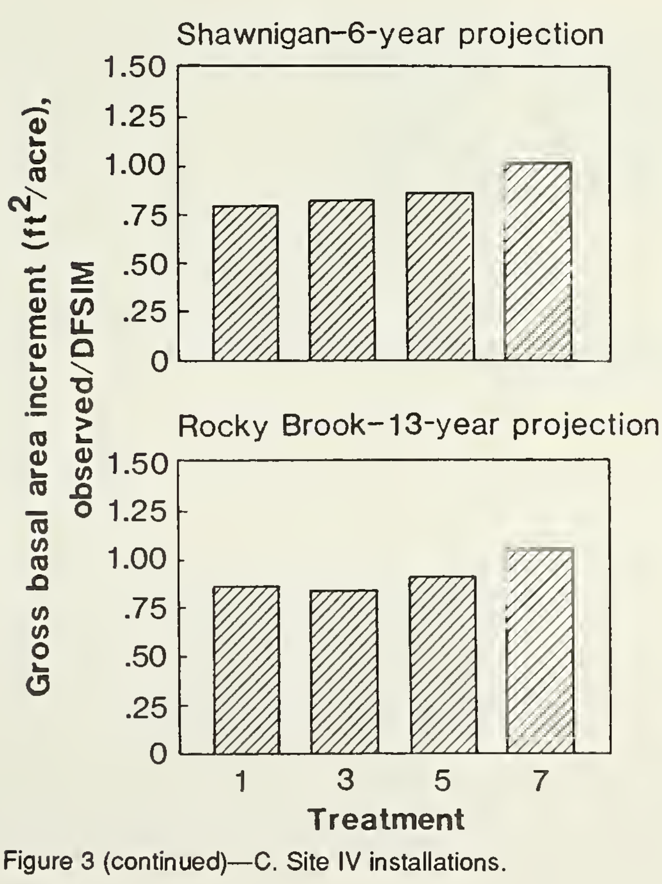

Figure 3 (continued)—C. Site IV installations.

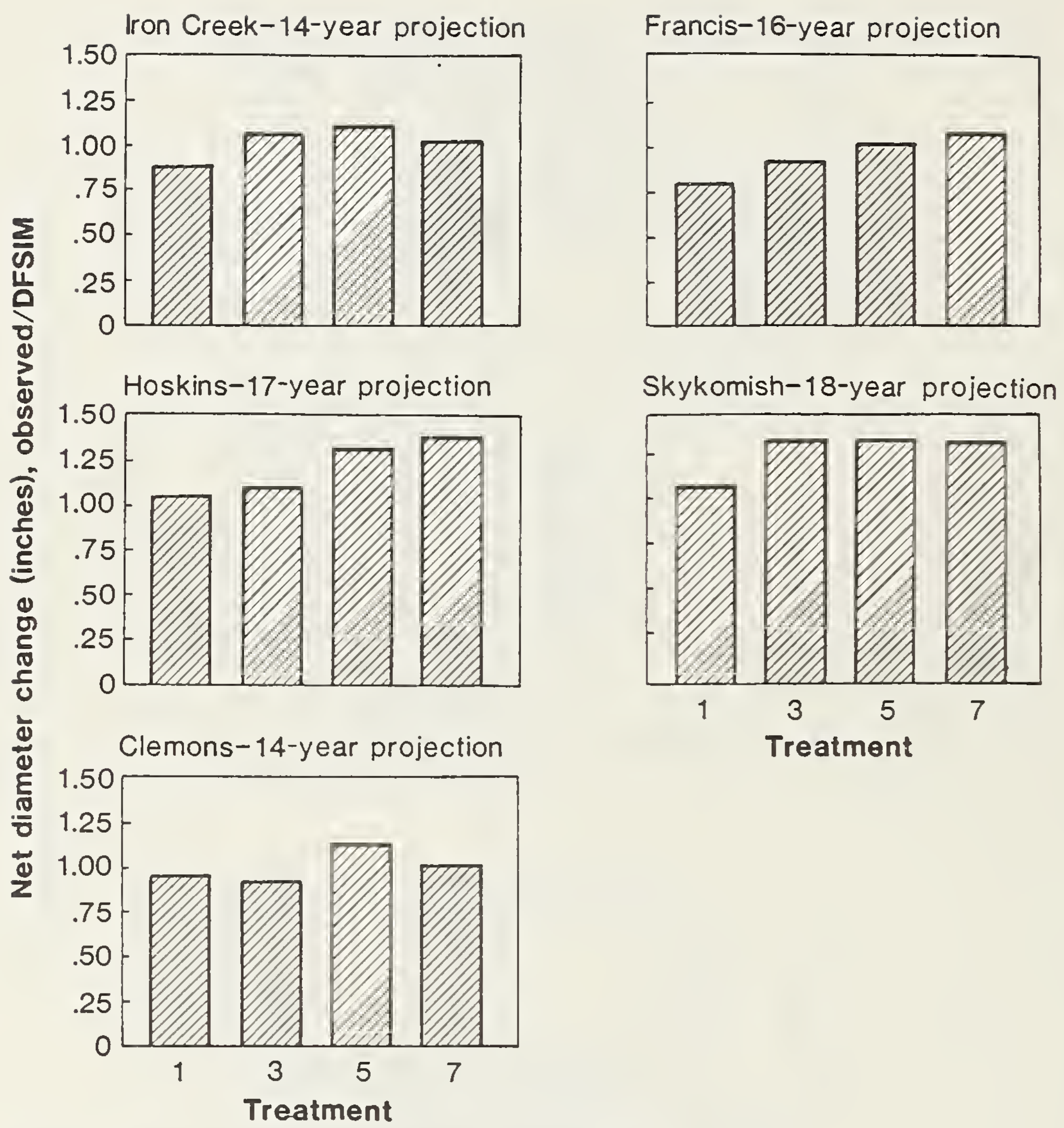

Figure 4—Ratios of observed net diameter change to DFSIM estimates, by treatment within installations, thinned plots, main stand routine. A. Site II installations.

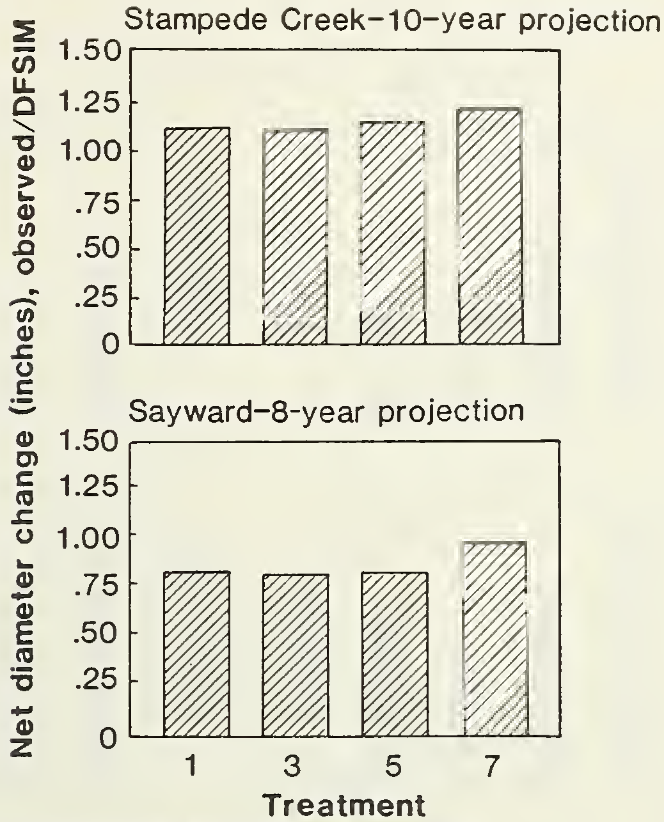

Figure 4 (continued)—B. Site III installations.

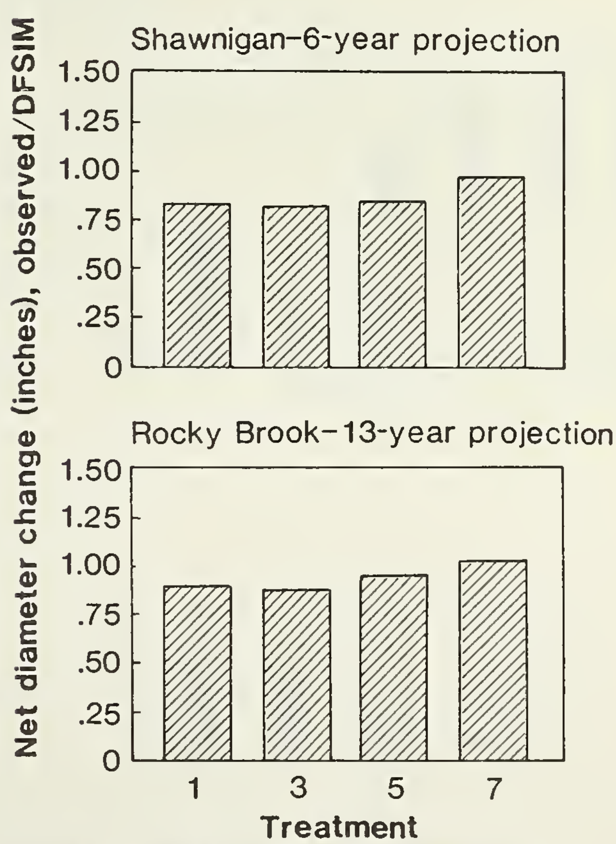

Figure 4 (continued)—C. Site IV installations.

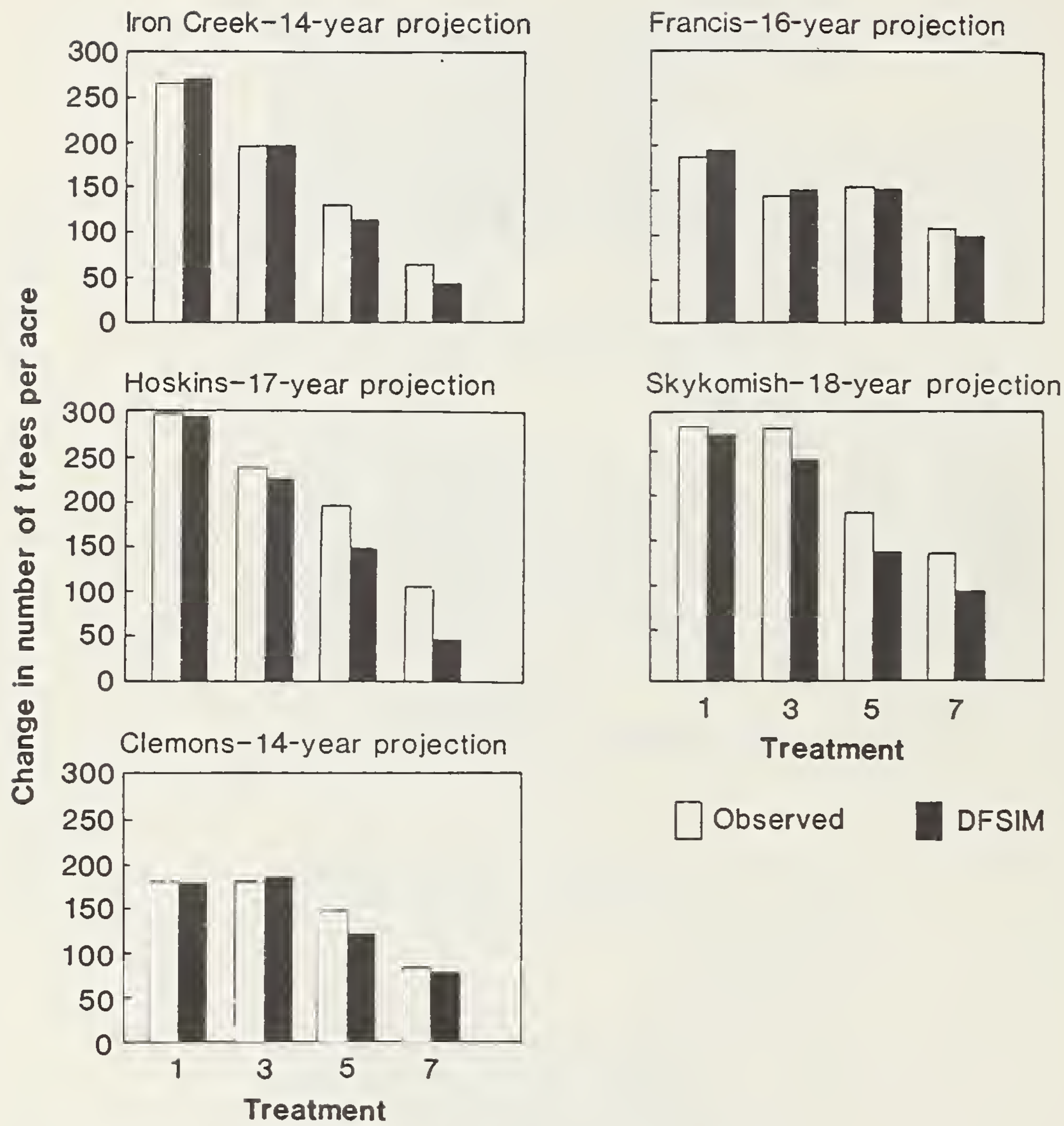

Figure 5—Comparison of observed net change in number of trees with DFSIM estimates, by treatment within installations, thinned plots, main stand routine. A. Site II installations.

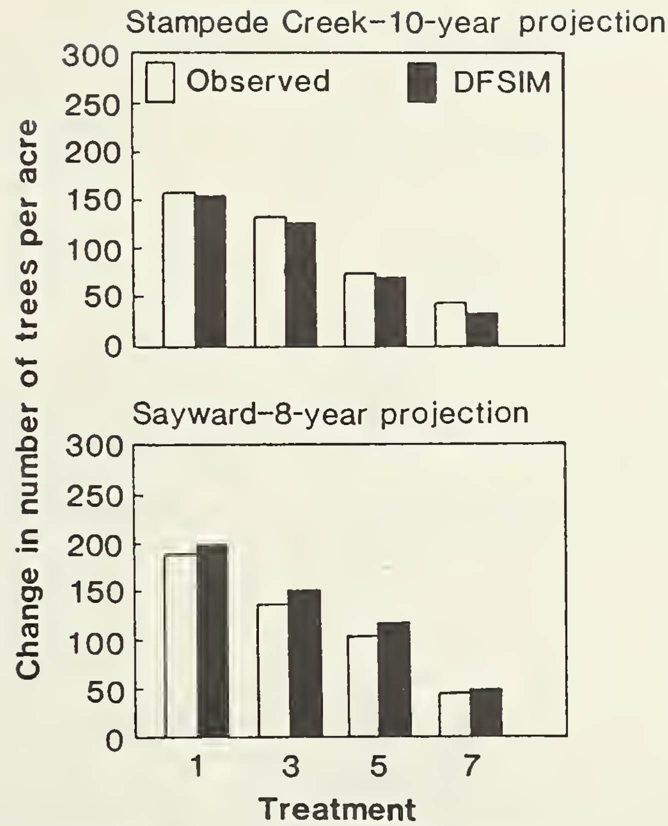

Figure 5 (continued)—B. Site III installations.

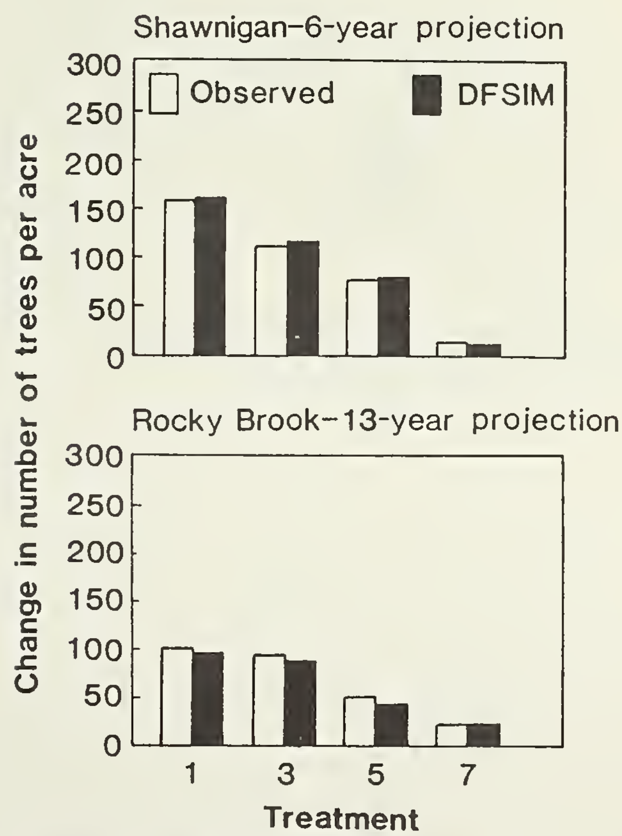

Figure 5 (continued)—C. Site IV installations.

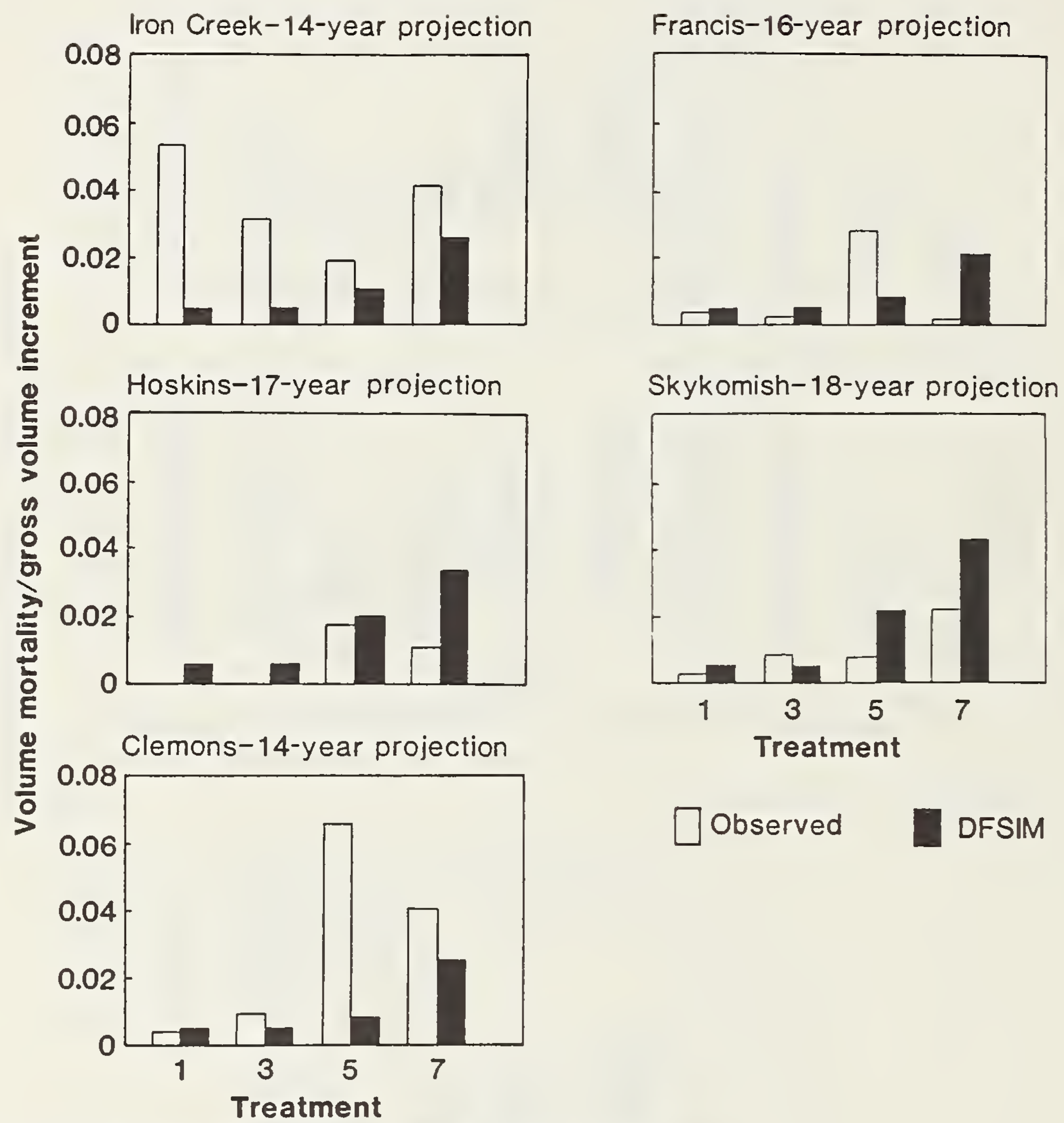

Figure 6—Ratios of volume of mortality to gross growth for observed values and for DFSIM, by treatment within installations, thinned plots, main stand routine. A. Site II installations.

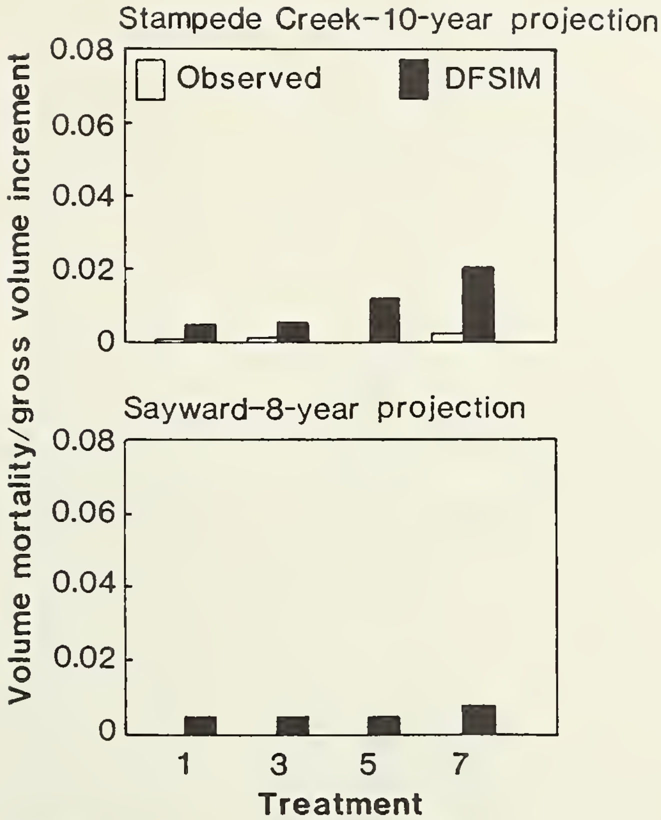

Figure 6 (continued)—B. Site III installations.

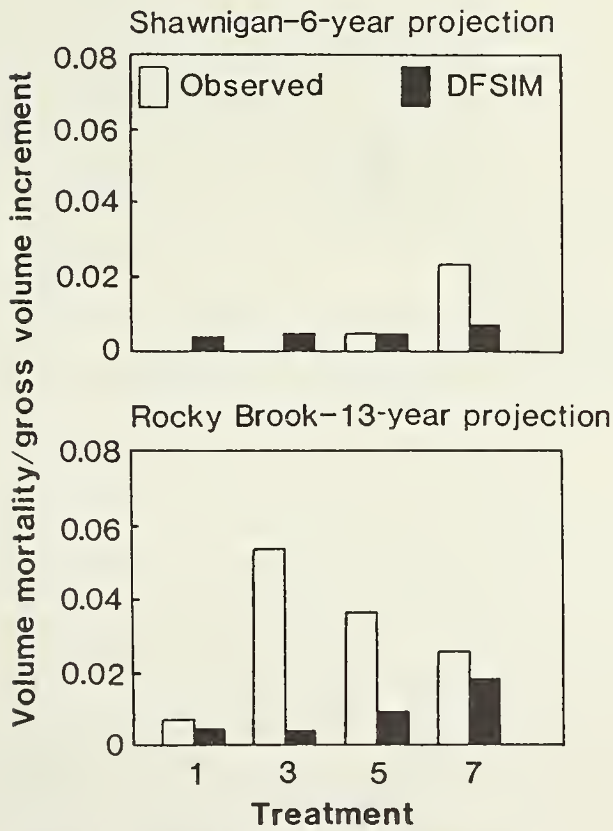

Figure 6 (continued)—C. Site IV installations.

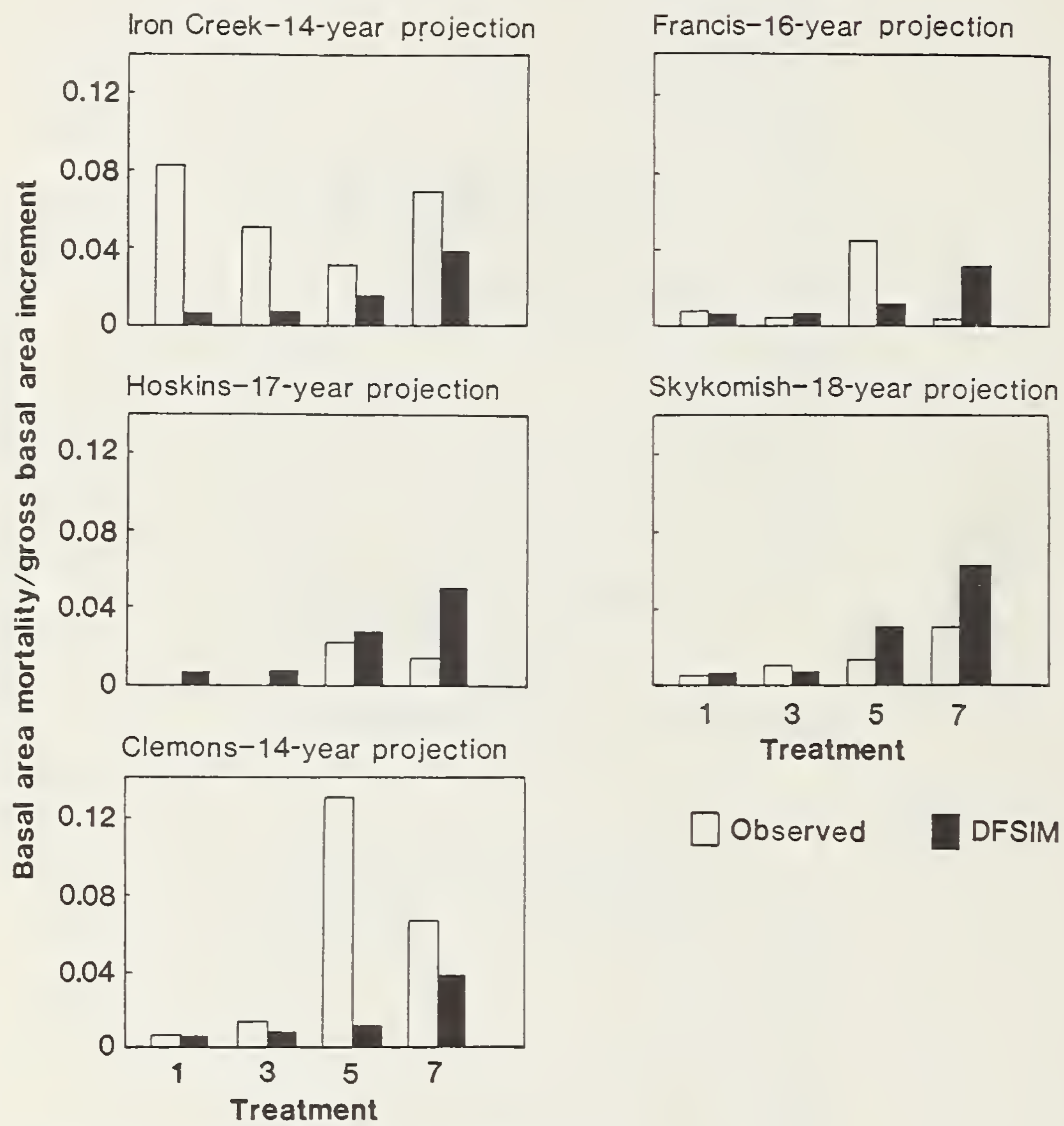

Figure 7—Ratios of basal area mortality to gross growth for observed values and for DFSIM estimates, by treatment within installation, thinned plots, main stand routine. A. Site II installations.

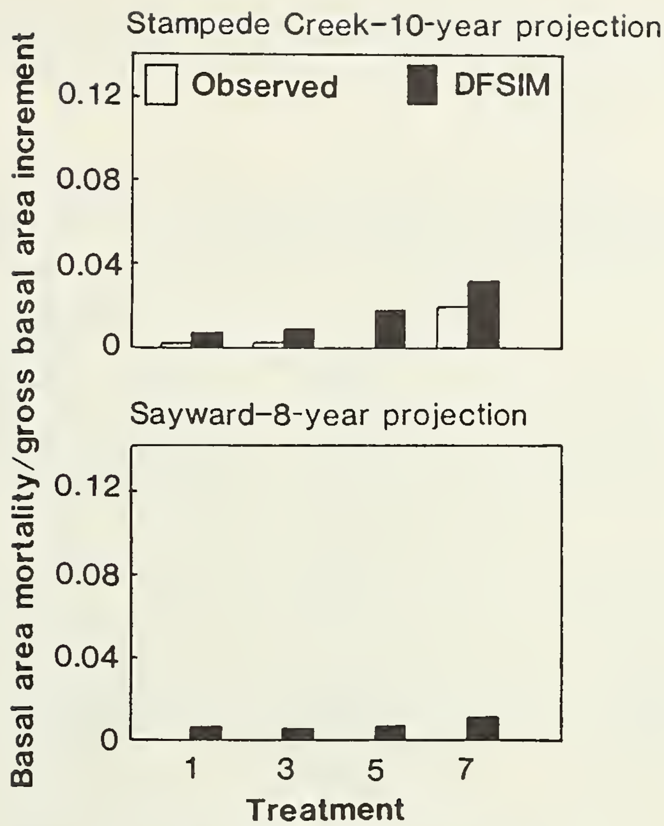

Figure 7 (continued)—B. Site III installations.

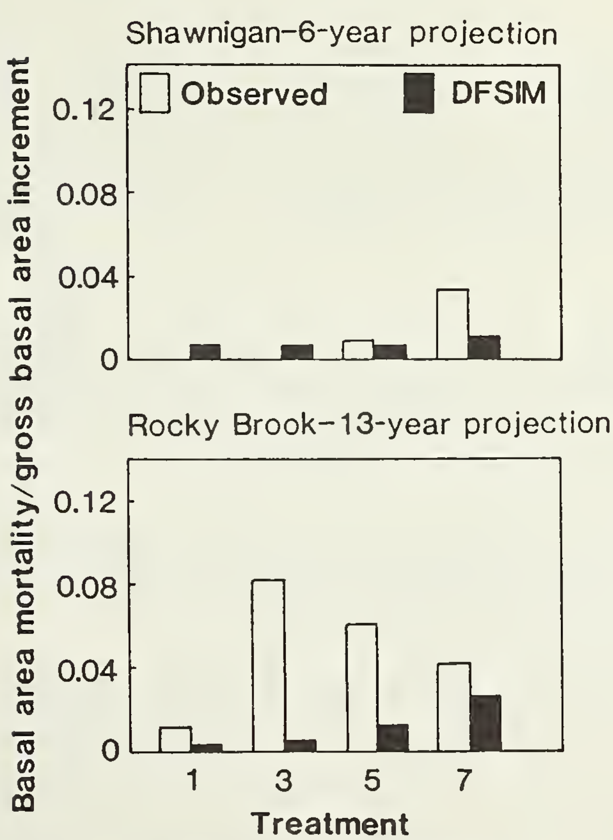

Figure 7 (continued)—C. Site IV installations.

Calibration period (juvenile stand).—A parallel series of projections was made for the calibration period only. Because all thinning treatments were treated alike at the calibration cut, results are shown as means for all thinning treatments, by installation (table 5 and figs. 8-10).

Table 5--Comparison of thinned plot mean increments with DFSIM estimates for calibration period only, thinning treatments 1, 3, 5, and 7 combined

Site	Installation	Projection period ages	Ratios of net increment: Observed/DFSIM		
			Volume	Basal area	D.b.h.
		years			
II	Iron Creek	19-23	0.97	0.98	1.04
	Clemons	19-22	.94	.92	.92
	Hoskins	20-23	1.16	1.27	1.23
	Francis	15-18	1.16	1.26	1.23
	Skykomish	24-28	1.14	1.15	1.13
III	Stampede Creek[1/]	33-38	1.05	1.21	1.18
	Sayward	22-26	.93	.95	.94
IV	Rocky Brook	27-31	.66	.61	.67
	Shawnigan	25-31	1.02	1.08	1.06

[1/] Stampede Creek was more than 5.6 inches in d.b.h. at establishment, and projection for calibration period uses main stand routine.

At all installations except Stampede Creek, initial diameters were less than 5.6 inches. Therefore, projections were generated by the juvenile stand routine in DFSIM, beginning with values of number of trees and basal area after the calibration cut and using smoothed height trends, as before.

At Stampede Creek, where postcalibration diameter was more than 5.6 inches, projections are based on the main stand routine and are directly comparable with results for the treatment periods.

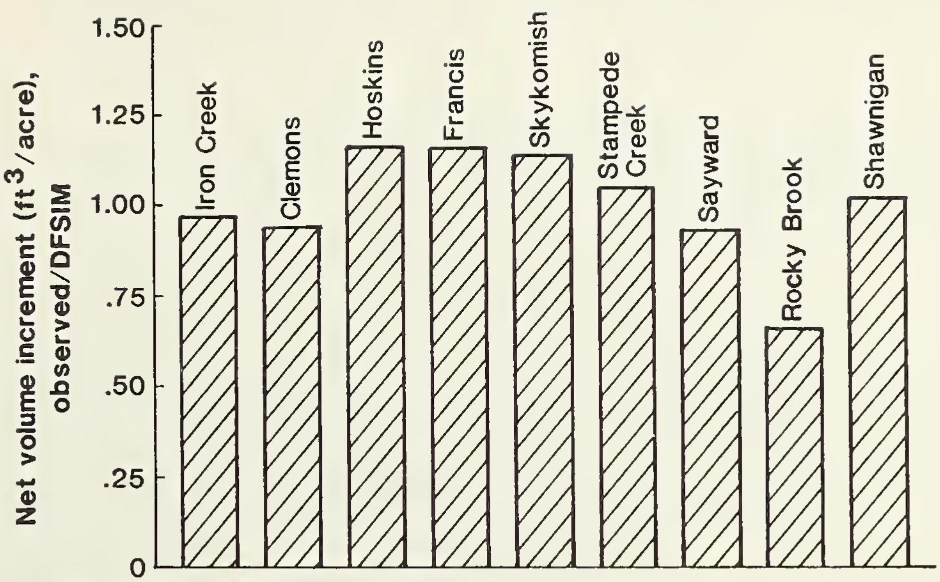

Figure 8—Ratios of actual net volume growth to DFSIM estimates, by installation; means of treatments 1, 3, 5, and 7 for calibration period only.

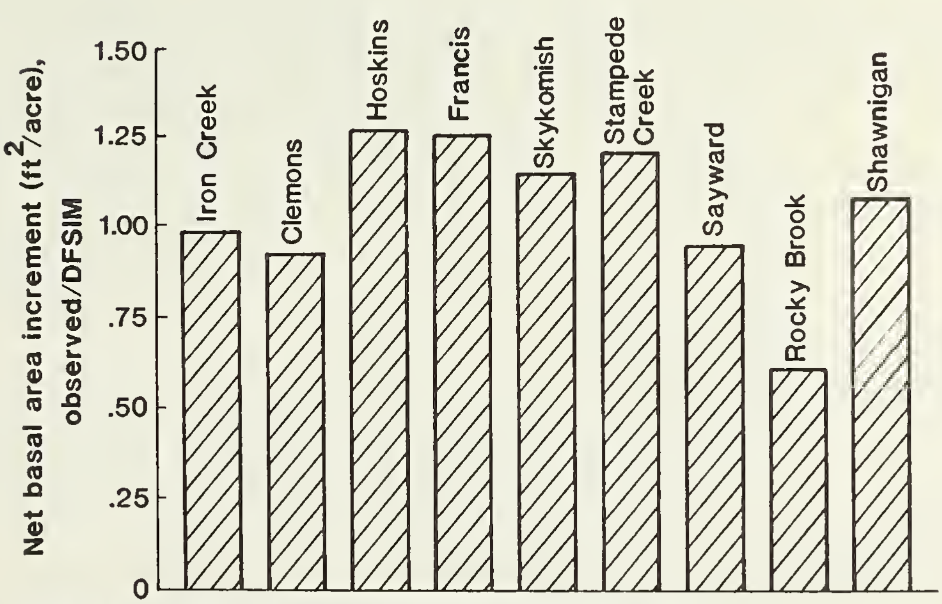

Figure 9—Ratios of actual net basal area growth to DFSIM estimates, by installation; means of treatments 1, 3, 5, and 7 for calibration period only.

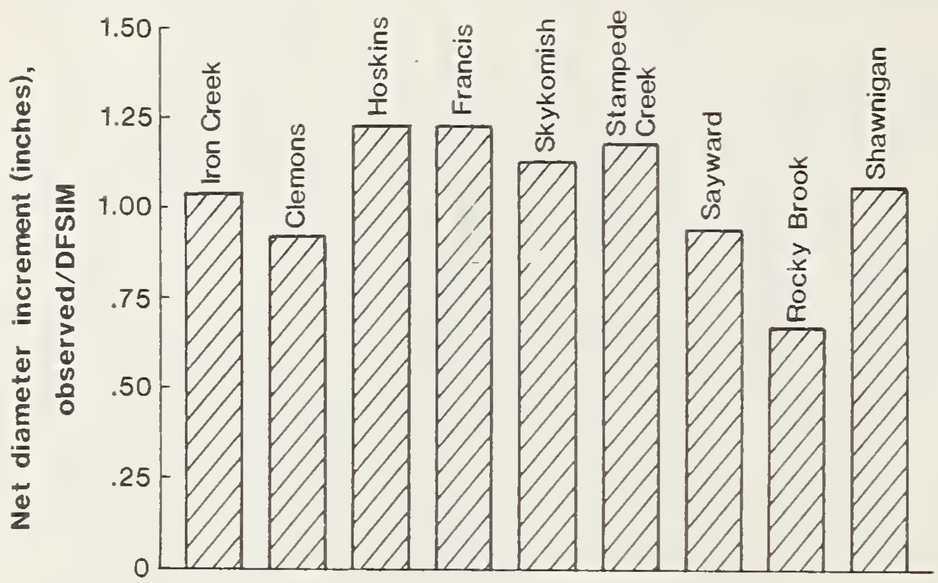

Figure 10—Ratios of actual net change in quadratic mean diameter to DFSIM estimates, by installation; means of treatments 1, 3, 5, and 7 for calibration period only.

Discussion

General notes.—Certain peculiarities of individual installations affect evaluation of results:

1. Skykomish, unlike other LOGS installations, is about 50 percent hemlock (*Tsuga heterophylla* (Raf.) Sarg.) by basal area. Average heights and diameters of the hemlock component are substantially less than those of the associated Douglas-fir component used as the basis for H40. Because species composition is quite different from that in the other LOGS installations and outside the stated range of applicability of DFSIM, little weight can be given to comparisons with this installation. Values are shown in tables and figures for people interested.

2. Iron Creek had substantial early mortality from bear damage (mostly during the calibration period) and, more recently, has had considerable mortality from root rot on several plots.

3. Rocky Brook suffered extensive snowbreakage shortly after establishment. More recently, extensive root rot has developed, scattered throughout the stand, and has caused one plot to be abandoned after the 1982 remeasurement.

Treatment period results.—

1. Gross volume increment: In the site II installations, averages across treatments of actual values and DFSIM estimates are comparable for Iron Creek, Clemons, and Francis; observed growth considerably exceeds predictions for Hoskins (and Skykomish). Figure 1 suggests that there is a consistent trend across treatments, with the higher growing-stock levels (treatments 5 and 7) having ratios of observed-to-predicted growth that are greater than 1.0, whereas lower growing-stock levels (treatments 1 and 3) in the same installations have ratios that are less than 1.0.

In the two site III installations, observed and predicted values appear in good agreement for the average of the two installations. Actual growth at Stampede Creek slightly exceeded predictions, whereas growth at Sayward was somewhat less than predicted.

Both site IV installations show substantially less gross volume growth than was predicted. Shawnigan is in better agreement with DFSIM than is Rocky Brook, possibly reflecting the known damage and disease problems at Rocky Brook. Again, the ratio of actual growth to predicted growth is highest at the highest growing stock level, treatment 7.

The differences across sites and across treatments are shown in an alternate form in figure 2, as regressions of ratios of observed/estimated gross volume increment on site index, fitted separately by treatment. (Skykomish is omitted because of its very different species composition and uncertain comparability.) Even with only eight installations, the regressions were significant at the 0.05 level for treatments 3, 5, and 7; the regression for treatment 1 was not significant.

Although the slopes of these lines differ significantly from zero, they do not necessarily represent an effect of site index only. Remember that (1) all treatments are begun from a common postcalibration low-density condition; (2) subsequently, treatments become increasingly different over successive periods as differing fractions of the gross growth on the controls are retained; and (3) stands progress through the sequence of treatment periods at rates that differ by site. Thus, the site II installations have now completed four to five treatment periods, whereas the site IV installations have completed one to two.

In the site IV installations, relative densities are not yet widely different and are still low. Therefore, the apparent relation of slopes to site index could in part reflect differences in average density associated with the different rates of stand development on different sites.

The order of elevations of the lines from treatments 1 through 7 indicates consistent differences associated with treatment (and stand density) for a given site index.

2. Gross basal area increment: The previous statements about gross volume increment also hold for gross basal area increment (table 2, fig. 3), although the range in values of the ratios of observed-to-predicted growth is greater, and the trend of increasing values with increasing growing stock appears more evident.

   Regressions of observed/estimated gross basal area increment on site index were also fitted, by treatment. Those for treatments 3, 5, and 7 were significant at the 0.10 level; the regression for treatment 1 was not significant. The relations were generally similar to those for the gross volume increment regressions discussed above, and the same interpretations apply.

3. Net change in diameter: Net change in stand average diameter shows a similar pattern (fig. 4). For the site II installations, the ratio of actual-to-predicted change exceeds 1.0 at Hoskins (and Skykomish) and is—on the average—about equal to 1.0 at Iron Creek, Clemons, and Francis. For the two site III installations, the ratio exceeds 1.0 at Stampede and is less than 1.0 at Sayward. Actual growth is less than predicted on both site IV installations.

4. Net change in number of trees: Net change in number of trees is compared in table 4 and figure 5. This is the combined result of removal of trees in thinning and loss of trees through mortality, primarily the former.

5. Mortality: Volume mortality and basal area mortality are compared in tables 1 and 2 and in figures 6 and 7. Observed mortality is highly erratic among treatments and among installations, and relative errors in predictions are large. Mortality losses in these thinned stands, however, have been minor (even though a few individual plots have been severely affected), and absolute errors are small. Mortality has had little effect on other stand statistics, and net growth in volume and in basal area (not shown) differs only slightly from gross growth.

Calibration period results.—Net volume, net basal area growth, and net change in stand average diameter appear to average close to DFSIM predictions (table 5 and figs. 8-10).

The most notable exception is Rocky Brook (site IV), for which growth during the calibration period was 30 to 35 percent below predictions. Rocky Brook, however, was severely damaged by snowbreakage at the start of the calibration period, and this could account for some of this discrepancy.

Growth for Hoskins and Francis (both site II) exceeded predictions by considerable margins.

Because DFSIM does not provide estimates of mortality for stands less than 5.6 inches in average diameter, basal area and volume mortality estimates are not available for the calibration period (except at Stampede Creek). Mortality has been minor at most installations, however, and gross growth relations would differ little from those for net growth, except possibly at Rocky Brook.

Comparisons for LOGS Controls

Analyses

Main stand routine.—Average diameters on control plots (treatment 9) are much less than those on thinned plots and do not reach 5.6 inches (at which point the main stand routine becomes operative) until considerably later than on the thinned plots. Three installations (Sayward, Rocky Brook, and Shawnigan) had not reached this point by the beginning of the most recent available growth period and are not included in these comparisons.

Age ranges represented by the data available from the remaining six installations are shown in tables 6 , 7 and 8, together with comparisons of actual growth with DFSIM estimates for gross growth, net growth, volume and basal area mortality, and net change in quadratic mean diameter and in number of trees.

Juvenile stand.—Comparisons of actual growth with predicted growth for the juvenile stand (D less than 5.6 inches) on the controls are seriously impaired because the available summaries do not separate ingrowth from survivor growth. Several installations have large numbers of ingrowth trees in an understory position on the controls, indicated by the sharp increase in recorded numbers of stems at the second and third measurements. Consequently, change in number of trees cannot be interpreted as mortality. And, because ending stand values include these ingrowth trees whereas initial values do not, change in diameter, volume, or basal area cannot be directly compared with DFSIM estimates generated from initial numbers and diameters.

Table 6--Comparison of observed values with DFSIM main stand routine projections of gross and net volume growth and mortality for controls only[1/]

Site, installation, and projection period ages (years)	Gross volume increment			Net volume increment			Volume of mortality		
	Observed	DFSIM	Observed/ DFSIM	Observed	DFSIM	Observed/ DFSIM	Observed	DFSIM	Observed/ DFSIM
	— ft³/acre —			— ft³/acre —			— ft³/acre —		
Site II:									
Iron Creek (30-37)	3,174	2,972	1.07	2,724	1,792	1.52	450	1,180	0.38
Clemons (26-40)	4,631	5,046	.92	4,031	4,325	.93	600	721	.83
Hoskins (27-40)	6,977	6,340	1.10	5,458	4,156	1.31	1,519	2,184	.70
Francis (25-37)	5,082	4,602	1.10	4,929	2,957	1.67	153	1,645	.09
Skykomish (28-46)	8,708	6,690	1.30	7,823	5,758	1.36	885	932	.95
Site III:									
Stampede Creek (43-48)	1,546	1,459	1.06	1,367	803	1.70	179	656	.27
Sayward[2/]									
Site IV:									
Rocky Brook[2/]									
Shawnigan[2/]									

[1/] Projections begin with actual basal area and number of trees at 1st measurement after attainment of average diameter of 5.6 inches or more.

[2/] Installation had not attained 5.6 inches in average diameter by the beginning of the last available growth period.

In this case, the largest number of trees recorded at any measurement (Nmax) was taken as an approximation of the actual initial number of trees, and DFSIM runs were made beginning with initial height and Nmax as initial number of trees. The program then generated a corresponding estimate of diameter. Stands were projected to the age at which the actual stand most nearly approximated 5.6 inches in diameter (or to the age at the last measurement, if this diameter was not attained).

Results are shown in table 8 as comparisons of actual and predicted volume, basal area, number of trees, and average diameter at the end of the projection period.

Discussion

Main stand routine.—It is evident that for the controls:

1. Observed gross growth and DFSIM estimates of gross growth in volume and in basal area are in reasonable agreement for all available installations except Skykomish (which is 50 percent hemlock and not directly comparable).

Table 7--Comparison of observed values with DFSIM main stand routine projections of gross and net basal area growth, basal area mortality, and net increment in quadratic mean diameter for controls only[1/]

Site, installation, and projection period ages (years)	Gross basal area increment			Net basal area increment			Basal area mortality			Net diameter increment		
	Obs	DFSIM	Obs/DFSIM	Obs	DFSIM	Obs/DFSIM	Obs	DFSIM	Obs/DFSIM	Obs	DFSIM	Obs/DFSIM
	— ft²/acre —			— ft²/acre —			— ft²/acre —			— inches —		
Site II:												
Iron Creek (30-37)	56.3	54.2	1.04	38.8	13.3	2.92	17.5	40.9	0.43	1.08	1.61	0.67
Clemons (26-40)	94.3	96.9	.97	73.3	74.0	.99	21.0	22.9	.92	2.64	3.21	.82
Hoskins (27-40)	120.8	104.2	1.16	66.5	32.5	2.05	54.1	71.7	.75	3.36	3.16	1.06
Francis (25-37)	106.7	96.8	1.10	100.0	35.5	2.82	5.9	61.3	.10	1.64	3.10	.53
Skykomish (28-46)	162.0	114.8	1.41	153.0	87.1	1.76	29.0	27.7	1.05	4.44	4.45	1.00
Site III:												
Stampede Creek (43-48)	30.5	25.1	1.22	21.2	4.1	5.17	9.3	21.0	.44	1.23	.85	1.45
Sayward[2/]												
Site IV:												
Rocky Brook[2/]												
Shawnigan[2/]												

[1/] Projections begin with actual basal area and number of trees at 1st measurement after attainment of average diameter of 5.6 inches or more. Obs = observed value.

[2/] Installation had not attained 5.6 inches in average diameter by the beginning of the last available growth period.

2. Actual mortality has been much less than DFSIM estimates at all installations except Clemons and Skykomish, where the initial numbers of trees and attained densities were relatively low.

3. Actual net volume and basal area growth have been considerably greater than the DFSIM estimates because of the differences between actual and estimated mortality.

4. Ratios of net change in average diameter to DFSIM estimates are highly erratic and are frequently much less than the expected value of 1.0.

The relatively poor estimates of net change in diameter and net growth in volume and basal area on the controls can be attributed to two main factors: the presence of understory trees and the effect of the upper density limit in DFSIM.

The DFSIM main stand routine assumes that there is no ingrowth (that is, all trees are included in the stand statistics available when the stand reaches 5.6 inches in diameter) and that any understory trees of a younger age class have been excluded.

Table 8--Comparison of observed values with DFSIM predictions at end of the projection period for the juvenile stand for controls only: volume, basal area, number of trees, and quadratic mean diameter[1/]

Site, installation, and projection period ages (years)	Nmax	Est. initial D	Volume			Basal area			Number of trees			D		
			Obs	DFSIM	Obs/DFSIM	Obs	DFSIM	Obs/DFSIM	Obs	DFSIM	Obs/DFSIM	Obs	DFSIM	Obs/DFSIM
	no./acre	inches	—ft³/acre—			—ft²/acre—			—no./acre—			–inches–		
Site II:														
Iron Creek (19-30)	1,193	3.49	5,170	4,238	1.22	209.4	169.6	1.23	1,183	814	1.45	5.7	6.2	0.92
Clemons (19-26)	687	4.42	2,749	3,214	.86	124.7	137.8	.90	662	627	1.06	5.9	6.4	.93
Hoskins (20-27)	1,727	3.50	5,411	4,080	1.33	228.6	177.1	1.29	1,272	1,087	1.17	5.7	5.5	1.05
Francis (15-25)	1,127	2.77	4,060	2,957	1.37	190.1	141.2	1.35	1,107	926	1.20	5.6	5.3	1.06
Skykomish (24-28)	594	5.07	2,460	2,586	.95	108.7	120.4	.90	594	570	1.04	5.8	6.2	.93
Site III:														
Stampede Creek (33-38)	1,010	5.29	3,557	4,484	.79	152.0	175.2	.87	1,010	792	1.28	5.2	6.4	.82
Sayward (22-34)	1,100	3.74	4,481	3,887	1.15	182.7	163.1	1.12	997	841	1.19	5.8	6.0	.97
Site IV:														
Rocky Brook (27-44)	1,335	3.48	5,095	4,212	1.21	220.6	170.6	1.29	1,333	835	1.60	5.5	6.1	.90
Shawnigan (25-37)	1,192	3.75	3,581	3,236	1.11	160.9	149.9	1.07	1,138	930	1.22	5.1	5.4	.94

[1/] Nmax is the largest number of trees recorded at either the initial measurement or at any subsequent measurement. Estimated initial D is the diameter estimated by DFSIM from the given initial height and the largest number of trees recorded at either the initial or any subsequent measurement. Obs = observed value; D = quadratic mean diameter.

At several installations (Iron Creek, Francis, Rocky Brook) the controls contain a substantial "tail" of small stems of tolerant species. This has little effect on values of volume and basal area, but it has a major effect on values of average diameter and number of trees and on estimates that depend on these latter values.

For comparisons consistent with DFSIM estimates, these understory trees should be excluded. Unfortunately, the existing LOGS data summaries do not separate ingrowth or understory trees, which are present only on the controls. It was not feasible to resummarize the LOGS data to revised standards specifically for these comparisons. This factor introduces some uncertainty in interpretation of differences for the main stand routine and major uncertainties about the juvenile routine, discussed later.

The principal cause of DFSIM overestimation of mortality and net diameter growth for the LOGS controls is clearly the way in which DFSIM treats stands at the upper limit of density.

DFSIM does not allow stands to increase in density beyond about RD70 (Curtis and others 1981, Curtis 1982), a relative density value originally derived as an average of the older untreated stands in the DFSIM data base. As stands approach this limit, DFSIM accelerates mortality to prevent further increase in relative density.

Curtis and Marshall (1986) have shown that the controls on all the LOGS installations except Clemons and Skykomish exceeded RD70--sometimes by wide margins--over most of the range within which the DFSIM main stand projection routine is operative (fig. 11). The DFSIM estimates therefore include sharply accelerated mortality.

The principal results are (1) an overestimate of mortality and a corresponding underestimate of net growth in volume and basal area, and (2) a major overestimate of net diameter growth (analogous to the diameter increase that results from a low thinning) because of the change in average stand diameter associated with the removal of too many small trees as mortality. It is no accident that the estimates of net diameter change are in good agreement with observed values at Clemons and Skykomish, which did not reach the RD70 density limit until very late in the observation period.

Selected uniform stands, such as those represented in the LOGS installations, clearly can frequently exceed the RD70 limit. It is not known whether or not densities as high as those attained at Hoskins, Francis, and Iron Creek (RD90-RD100) can be maintained for an extended period, but they clearly are possible and even probable in unthinned plantations and very uniform natural stands.

Juvenile stand routine.—In general, DFSIM predicts a greater reduction in number of trees than has occurred (assuming that Nmax was close to the actual initial number). Differences in other values (volume, basal area, diameter) are associated with these differences in predicted numbers and probably arise from them.

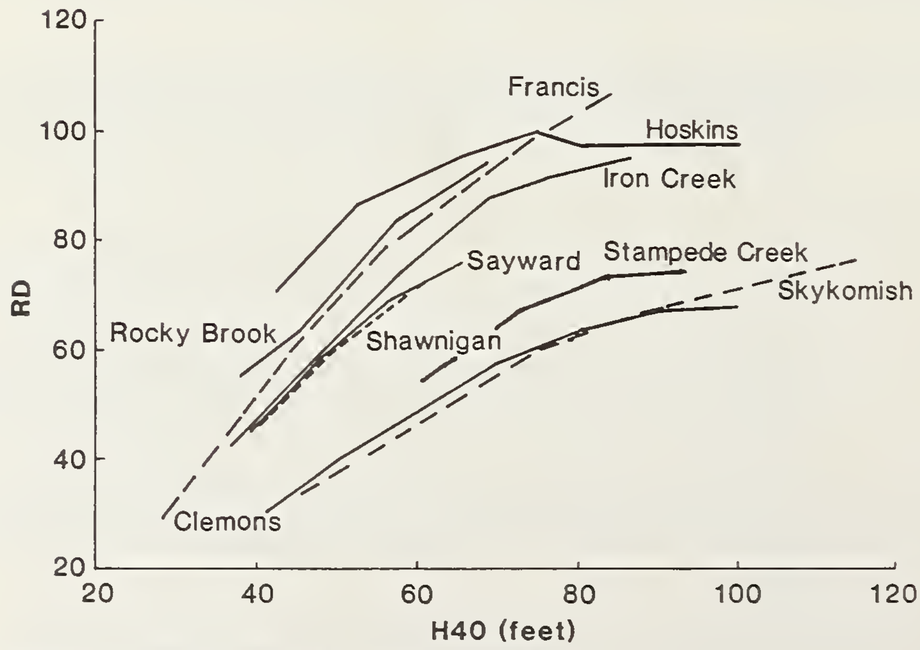

Figure 11—Trends of relative density (RD) over top height (H40) on LOGS controls, by installation.

Supplementary Comparisons

Supplementary comparisons were made with the Wind River spacing test (Reukema 1979) and the 0.5-acre plots from the University of British Columbia spacing test (Reukema and Smith 1987), with data made available by Donald L. Reukema and J.H.G. Smith. The first represents a long period of observation on a low site (site IV), whereas the second provides similar information, for a much shorter observation period on an excellent site (site I). Detailed results are not presented in this report, but they appear generally comparable to those from the LOGS data.

For the main stand routine, DFSIM somewhat overestimated gross volume growth, while seriously overestimating mortality at the closer spacings. The combined result is a serious overestimate of diameter growth at close spacings, but estimates of net volume growth that are fairly close to observed growth.

In the very limited comparisons possible, the juvenile stand estimates appeared consistent with the observed values.

Conclusions

The conclusions that can be drawn from these comparisons are necessarily limited because we have only eight locations, plus one (Skykomish) of doubtful comparability in species composition. Nonetheless, these comparisons do bring out several points of interest.

Thinned Plots

Overall, agreement with observation seems surprisingly good when we consider how different the LOGS thinned stands are from the majority of the data that went into DFSIM.

An apparent bias, associated with differences between treatments, probably represents the effect of differences in stand density. This is most clearly seen in the site II installations, where the ratios of observed growth to predicted growth are clearly higher in the higher density treatments.

There is also an apparent tendency toward overestimation on poor sites and underestimation on good sites; however, because differences in density of given treatments correspond to the different rates of development on different sites, this could be in part a concealed effect of density. With the site IV data limited to two installations--one of which now has only one treatment period available, and the other has two--no real conclusions can be drawn.

At the relatively low stand densities found on the thinned plots, mortality is a minor factor in stand development, and the DFSIM estimates of mortality are in acceptable agreement with observation.

Controls

Somewhat surprisingly, estimates for controls have generally shown poorer agreement with observation than have those for thinned plots. This is due in part to the presence in some controls of substantial amounts of ingrowth and small understory stems of tolerant species, not specifically identified or separated in summaries. These trees, which should be excluded from comparisons, distort the number of trees and average diameter values and introduce uncertainties in comparisons.

A more clearly identifiable factor and a serious source of bias in DFSIM appears to be the fixed upper limit on relative stand density and the accelerated mortality used to prevent stands from exceeding this limit. This causes serious overestimates of diameter increment in dense stands and also affects net volume and basal area growth values.

The present limit of RD70 is a somewhat arbitrary average of values from the older untreated plots used as controls in various past thinning and fertilization studies. It is very close to the "normal" of McArdle and others (1961), which is widely accepted in the region for natural stands; however, mortality is probably greater and the limit on attainable stand density may be lower in natural stands than in uniform young stands, such as those that are included in LOGS and that are likely to be common in the future.

Clearly, vigorous, uniform young stands frequently develop relative densities well above RD70, in the absence of density control. The upper limit appears to vary among stands, for reasons unknown--a fact noted by others (Assmann 1970, King 1970).

Possible Changes in DFSIM

These comparisons, combined with others, suggest a need for modifications to the DFSIM stand simulation program.

First, the thinned plot comparisons suggest possible biases in the growth-stand density relations for thinned stands, and a possible but not clearly separable bias in relation to site. Modifications to correct this will have to await an updating of the data base with additional data for thinned and spaced stands, and a general reworking of the component relations. Such an update of the data and reworking of the simulator are highly desirable, both to correct perceived problems and to extend the range of applicability of DFSIM; but these do not appear immediately feasible because of current resource constraints.

A second, more clearly defined problem—and one that may be amenable to a "quick fix"—is the matter of the upper density limit. These and other comparisons have shown that young, uniform stands can frequently exceed the present limit of RD70 and that the current procedure of constraining stands to this limit by accelerating mortality can introduce substantial bias and can lead to unrealistic estimates for dense stands. The present density limit and the procedure used to constrain growth as stands approach the limit are both somewhat arbitrary. For vigorous uniform young stands, the default value for this limit should probably be higher than the RD70 used in the present version of DFSIM. A desirable refinement would be a provision allowing the user to alter the upper density limit to agree with local experience.

It may also be feasible to alter the density control routine so that gross growth is reduced concurrently with the acceleration of mortality as the density limit is approached. This would reduce or avoid the tendency to overestimate diameter growth of stands close to or beyond the density limit.

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Initial stand statistics for the levels-of-growing stock-study installations were projected by the Douglas-fir stand simulation program (DFSIM) over the available periods of observation. Estimates were compared with observed volume and basal area growth, diameter change, and mortality. Overall agreement was reasonably good, although results indicate some biases and a need for revision of the upper density limit in the DFSIM program.

KEYWORDS: Simulation, projections (stand), model validation, statistics (stand), growing stock (-increment/yield, Douglas-fir, *Pseudotsuga menziesii.*

Pacific Northwest Research Station
319 S.W. Pine St.
P.O. Box 3890
Portland, Oregon 97208

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